

A NEW DENDROMETER

BY

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There is a growing demand for a satisfactory dendrometer, or instrument which will measure the diameter of trees at points out of reach from the ground. An indication both of the wide demand and of the requirements which such an instrument must meet may be gained from a consideration of the following instances.

In certain regions, United States Forest Service timber estimators have made use of a volume table based on a diameter measurement at the top of the first sixteen-foot log instead of at the conventional breast-high point. This was on account of the abnormal form of the badly burned butts, which made a lower measurement both uncertain and a poor index of volume. Considerable trouble resulted through inability to check the ocular estimates of diameters except by uncertain methods of measuring at breast height and subtracting the estimated taper. For such cases there is needed a dendrometer of moderate precision, large range, considerable rapidity, lightness, and portability.

Many volume tables are based on a measurement of height to a certain fixed cutting limit, such as six, eight, or ten inches top diameter. From the ground it is often more difficult to identify this point than it is to estimate its height, and considerable errors result. Instruments of only a small range of sizes are needed, and in fact for a given volume table, or a consistent set of tables, an instrument that can be fixed and adjusted for a single diameter would serve the purpose.

Other volume tables are based on height to the limit of merchantableness. This limit, however, varies widely in different regions, even for a single species, and to use such a volume table accurately one must know the top diameter corresponding with each value of the table and estimate heights accordingly. Exactly the same type of in-

strument is required as in the last case, save that a slightly larger range of diameters is needed and a fixed adjustment for a definite size is not adequate.

Many Pacific coast volume tables are based on diameter, height, and taper. While the first two factors are measured, at least occasionally, the last is usually a matter of guesswork entirely. The instrument needed to strengthen this part of the work is a dendrometer possessing the qualities above mentioned, and in addition one which works independently of distance, since both horizontal distances and heights will usually be but roughly approximated.

In many scientific studies of growth on permanent sample plots in this country periodic measurements of diameters breast-high and

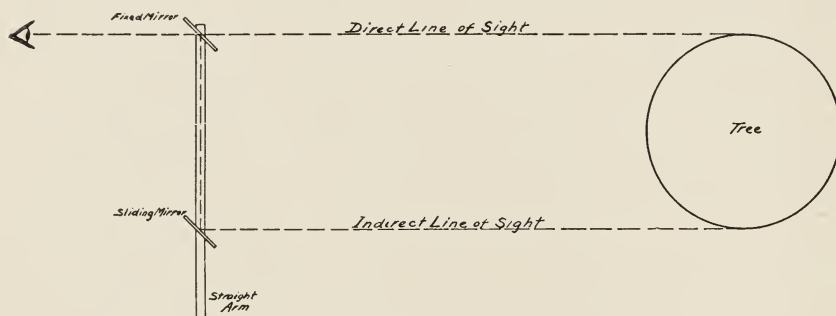


Fig. 1

heights are being secured, and growth in volume is being calculated from these data by means of a single volume table for each species. As a result, whatever growth results from a change in tree form is being neglected. A dendrometer is needed of considerable precision, but not necessarily so portable or rapid in action as in the previous cases. Its range in most cases need not be great, since the more important growth problems are connected with second-growth timber or, at least, with trees below a certain diameter limit.

Schiffel's formula for obtaining volume has not been sufficiently tested for most American species, but it is regarded as probably having a high value in many cases. It requires a measurement of diameter at a point half way up the bole, and hence a dendrometer. The qualifications of a satisfactory instrument will naturally depend on the character of the work being done.

All these instances indicate that it is not due to the absence of a real need that dendrometers are practically unknown in America. It seems obvious, rather, that no existing type satisfies the conditions

above outlined. The following pages describe an instrument based on a somewhat different principle from those previously devised, which will be seen in a large measure to meet these requirements.

It consists essentially of a straight arm upon which are mounted two small mirrors, both at an angle of 45 degrees with the axis of the arm, parallel to each other and facing in opposite directions (see fig. 1). One mirror is fixed at one end of the arm, while the other is mounted on a slide which travels along the arm. Graduations permit a direct reading of the distance between the mirrors.

The principle is indicated by figure 1 which shows the relative position, as seen from above, of tree, observer's eye, and of the instrument when in use. It will readily be seen that the instrument is closely akin to the ordinary calipers in principle, except that for the parallel fixed and movable arms of the calipers are substituted two parallel lines of sight. The direct line of sight passes just above the upper edge of the fixed mirror from eye to one edge of the tree, while the indirect line of sight is reflected in each of the two mirrors to the other edge of the tree. That the two lines of sight are parallel and hence that the distance between the mirrors is equal to the diameter of the tree is too self-evident to demand geometrical demonstration.

In use the observer holds the dendrometer arm horizontal (if the tree is in the normal vertical position) with one of the mirrors in line between his eye and the left-hand edge of the tree at the point to be measured. He then catches the reflection of the second mirror in the first, thus bringing the arm into a line perpendicular to the line from eye to tree. By sliding the second mirror in or out, the right-hand edge of the tree will become visible in it. The adjustment is now continued until the left-hand edge as seen directly and just above the fixed mirror, and the right-hand edge as seen indirectly through the two mirrors, are in a straight line, one immediately above the other. The distance between the mirrors as read from the graduations on the arm is then the required diameter.

The advantages and disadvantages of the instrument are evident.

- a. It is direct reading.
- b. The distance from the observer to the point observed does not have to be determined.
- c. As a result, the instrument is rapid in use.
- d. It may be set for a given diameter, regardless of distance.
- e. It is light in weight and of convenient shape for carrying; it is more portable than a pair of calipers of the same range.

- f. It will measure only a moderate range of sizes.
- g. While very accurate for a hand instrument, it is not capable of extreme precision.

The reason for the last two statements will be explained in the following pages.

It is evident that it will meet quite well the requirements already outlined. It fails at two points only—its moderate range might prevent its use in very large timber, and its lack of absolute accuracy may militate against it for very precise, scientific work.

Most of the errors of such a dendrometer are easily kept negligible. Of course at any considerable distance, small variations of diameter are imperceptible and cannot be measured. Since the minimum visual angle for normal eyes is one minute, two-tenths of an inch is the smallest variation recognizable at a distance of fifty feet. This consideration applies equally to all dendrometers which do not involve telescopic observations, and the use of a telescope at once means a heavy and awkward instrument.

If the arm is not held at right angles to the direct line of sight, the graduations on the arm will no longer measure the distance between mirrors along the indirect sight line, nor will this distance agree with the desired diameter. However, this error can never be large since, unless the arm is in approximately the correct position, the second mirror cannot be seen at all in the first, and to center its image therein is an instinctive proceeding. For more precise work, however, an additional aid may be afforded by vertical lines scratched into the backing of each mirror at its exact center, which are to be brought into apparent coincidence when the instrument is in use. An alternative method of obtaining the same result is to mask the fixed mirror with dark paper until, at the most convenient distance from the eye, the whole of the movable mirror can just be seen in it. The position of such a mask is shown in figure 2, A.

A rotation of the dendrometer about the axis of the arm will, of course, raise or lower the indirect sight line running from the instrument to the tree. Here again, however, unless the position is essentially correct, the image of mirror 2 cannot be found in mirror 1. The error resulting, moreover, is merely the amount of taper that occurs between the points observed by the direct and indirect sight lines, which is usually negligible.

Of course, if the two lines of sight are not parallel, serious errors will result. This depends on having the two mirrors parallel and is

in part a matter of adjustment. Two opposed adjusting screws must therefore control the rotation of one of the two mirrors. Adjustment is simple. Some target of known diameter or breadth (a sheet of paper against a dark background will serve) is observed with the instrument set at the corresponding diameter. The mirror is then rotated by its adjustment screws until the two edges appear in line. This process is delicate, but neither complicated nor difficult.

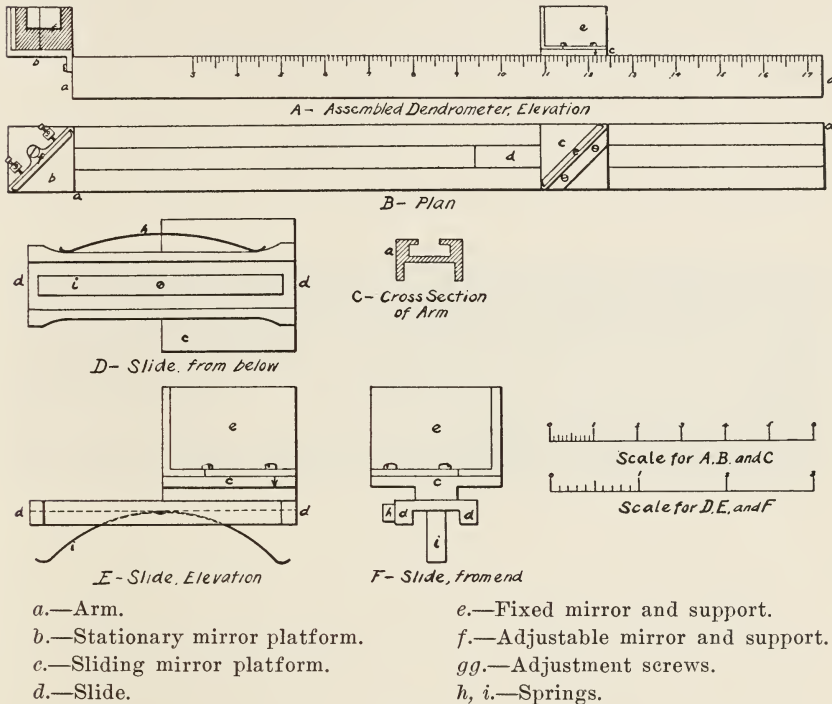


Fig. 2

The one error which dominates all others is that due to a failure of the arm to be absolutely straight. This is unfortunately a matter of instrumental construction and not of adjustment, and the difficulty of making this arm straight is surprisingly great. It is obvious that almost imperceptible deviations will result in slightly diverging or converging sight lines and in increasingly serious errors in the diameter readings, as the distance at which the measurement is taken is lengthened. In the instrument described the maximum error from this source is .6 inch when used at fifty feet; it is doubtful if materially better results are obtainable. This is not excessive. Even with a transit read to the nearest minute, the diameters fifty feet away can be read

but to the nearest .2 inch. With a hand instrument of the common type which involves the measurement of the angle between two sight lines it is difficult to provide for an accurate reading closer than to the nearest 10 minutes. This means that at the same distance 1.7 inches would be the minimum recognizable difference in diameter.

Figure 2 shows the details of construction.¹ *a-a*, of *A*, *B*, and *C*, is the straight arm which is made of a casting of aluminum alloy. The straight edge is the back surface of the slot which is recessed into the upper surface of the arm, as is best seen in the cross-section. This cross-section is perhaps unnecessarily heavy, but was so designed to insure as perfect a straight edge as possible. In this slot travels the slide *d* shown in detail in *D*, *E* and *F*, which are drawn to twice the scale of *A*, *B* and *C*. This slide is equipped with two springs, *h* and *i*, which hold it against the back and upper surfaces of the slot. Upon

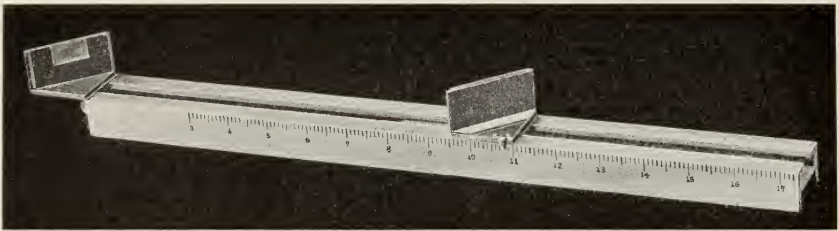


Fig. 3

it is mounted the mirror platform, and mirror *e* turned to an angle of 45 degrees to the axis of the slide. At the end of the arm a second fixed mirror platform, *b*, is mounted on which is the second mirror, *f*, which can be adjusted by the two opposed adjusting screws, *g-g*. This mirror is shown with both center line and mask, though both are hardly necessary. The scale is readily seen in *A*. This is read by means of the small arrow engraved on the side of *c*, as shown in both *A* and *E*. In *A* the reading, for example, is 12.2—.

If the weight of the instrument, slightly less than 27 ounces, is found objectionable, it would probably be safe to lighten materially the cross-section of the arm by reducing both the depth of the downward projecting ribs and the thickness of the lateral walls. The mirrors also, as shown, are very generous in size, and might be reduced to about two-thirds the indicated dimensions without introducing any serious difficulties through restricting the field of vision.

¹ To Mr. V. Arntzen of the Civil Engineering Laboratory of the University of California, credit is due for the major part of the detail of design.

The instrument shown has an arm eighteen inches long and will read diameters from three to seventeen inches. A longer arm is, of course, possible, but at about thirty inches a point is reached at which the adjustment of the sliding mirror when held in working position would become awkward. This may then be taken as the practical limit, unless some modification of the principle be adopted. This range will be sufficient for a great deal of the work to be done. If less accuracy is required, measurements of double this size can be secured by taking the center of the tree as the target for the direct line of sight, instead of the left-hand edge, and bringing the reflection of the right-hand edge in line with the center point. This operation can be performed more accurately than might at first be supposed, and the method, while rough, is probably quite adequate for work in connection with the Pacific coast volume tables already mentioned, in which taper is a factor.

A quick field test of the parallelism of the sight lines consists in measuring the same diameter at two different distances. The readings should, of course, be identical, or rather, since a small observational error is unavoidable, as nearly identical as would be two consecutive measurements from a single position. If an error is found and it is not convenient to make the proper adjustment it may be simply and quite accurately allowed for, by taking consecutive observations at two known distances. For example, suppose the first reading is 14.8 inches and the second reading taken at one-half the distance is found to be 14.4 inches. Since the error is proportional to the distance, a reduction of the distance to one-half must also reduce the error to one-half. The reduction in error is .4 of an inch, the total original error must have been .8 of an inch, and the correct reading is therefore $14.8 - .8 = 14.0$ inches. Where the errors are small, the major portion of them can thus be eliminated, even if the distances are estimated instead of measured.

A modification of this type of dendrometer is suggested for timber survey crews which are using volume tables to a fixed top-cutting limit such as six or eight inches. All that is necessary in such cases is the pair of parallel mirrors, one of which is adjustable, mounted six or eight inches apart on any light but rigid base not affected too readily by changes of temperature or humidity. By thus eliminating the straight edge and slide of the instrument herein described, the most serious source of error will be eliminated and the cost largely reduced.

